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Simultaneous measurement of electrical and thermal properties: Application to margarine

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Abstract. An experimental set-up for simultaneous measurement of thermal and dielectric properties of pasty materials, and in particular of margarine is proposed. The objective of the study was to observe simultaneously how the above mentioned properties change when margarine undergoes temperature changes within a temperature range that also encompasses its melting point. The PVDF pyroelectric sensor in combination with the plane plate capacitor was used for simultaneous measurement avoiding thereby problems arising from differences in both, sample's quantity and specific portion taken, the illumination level, heating, etc. As result of temperature variations both, the electrical and thermal properties of margarine were shown very sensitive to the structural changes. The reversibility of the modification process was observed. The results obtained with the set-up for simultaneous measurements were compared to those acquired by the methods capable of measuring each of the two properties separately.

1. INTRODUCTION

Margarine, a water-in-oil emulsion, exhibits a complex behaviour when undergoing temperature changes within a range that encompasses the melting of fat, breaking up of emulsion and the separation of water and oil phases. These phenomena, as well as compositional and micro-structural aspects have been studied by various modern characterization techniques including Raman [1], laser [2] and emission spectroscopies [3], the nuclear magnetic resonance (NMR) [4], the photopyroelectric method [5-7], differential scanning calorimetry [8], etc. However, the availability of other techniques capable of providing either complementary or confirmative information is regarded as very useful. Additionally, novel, simple non-destructive methods capable of detecting the aforementioned changes in margarine (and other pasty-like foods) in a sensitive and reproducible fashion are still lacking. Thermal and electrical properties of such materials were shown very sensitive to changes following the temperature variations.

This paper discusses an experimental set-up suitable for simultaneous measurement of thermal and dielectric properties of margarine. In doing so the plane capacitor (a conventional device used for determination of the dielectric constant) was combined with the pyroelectric sensor. Such low cost system is not only simple and easy to handle but has an advantage in the sense that thermal and electrical properties can be determined for the same portion of the sample and at the same time, using the same set-up. To our knowledge it is for the first time ever that these properties are measured simultaneously. The results of the two experiments in which both properties have been obtained independently were compared with the outcome of the "simultaneous" investigation.

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2. METHODOLOGY

Commercial margarines (without salt, fat content approximately 80%) purchased in the local supermarket, were initially studied in separate experiments to obtain values for dielectric constant and photopyroeletric signals (PPE). For simultaneous measurement of dielectric and thermal features on the same samples performed at the later stage of the experiment, the "coupled configuration" with the special unique cell was used. All the experiments were carried-out as a function of temperature.

The dielectric constant measurements were conducted using an automatic LCR meter (model PM 6304). The pyroelectric signals in the SPPE (standard configuration, i.e. incident radiation impinges on the sample) as well as in IPPE (inverse configuration with radiation hitting the pyroelectric sensor first) geometries were recorded using a 5210 EG&G Lock-in amplifier and a modulated beam (at 5Hz) of the HeNe laser.

All measurements were performed within temperature varying between 10 ^{o}C and 60 ^{o}C and controlled by a temperature controller model LFI-3551 (Wavelength Electronics) coupled to a Peltier element.

2.1 Set-up for dielectric measurements

Experiments were performed using a plane plate capacitor with the 1 mm thick dielectric material between the plates acting as a sample. The capacitor plates were made from steel to eliminate possible chemical reaction between the plates and fatty acids present in margarine.

2.2 Set-up for photopyroelectric measurements

The standard photopyroelectric configuration SPPE was applied to monitor the thermal behaviour of margarine. A 110 µm thick PVDF foil, metalized in at both sides, was used as the pyroelectric sensor. A black-ink-painted, thin aluminium foil was put atop the surface of the 475 µm thick sample to assure the absorption of the radiation at the surface layer. The modulation frequency of 5Hz light ensures the conditions imposed for thermally thick sample and sensor [9].

2.3 Simultaneous dielectric and photopyroelectric measurements

Capacitor described in 2.1 but with one of its plates being replaced by the PVDF foil was used in this experiment. In such manner, the metalized side of pyroelectric acts as one of the plates in the measurement of dielectric constant (see Fig. 1.). The lock-in measures the IPPE signal[10] at 5 Hz while the LCR meter detects capacitive response to the applied 10 kHz signal. The two signals, being completely independent of one another, were processed by a computer.

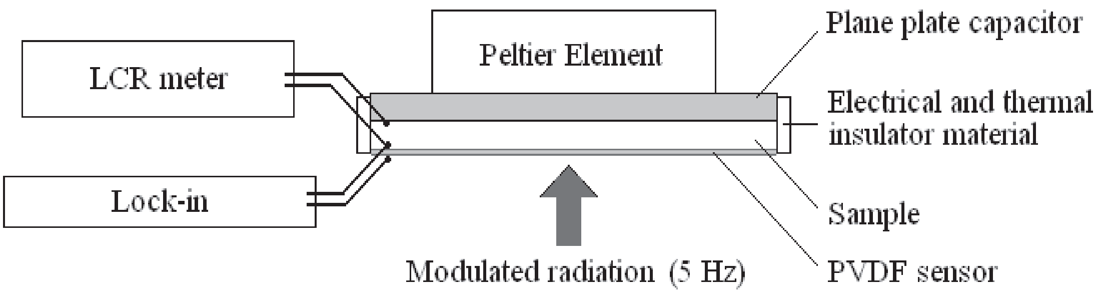
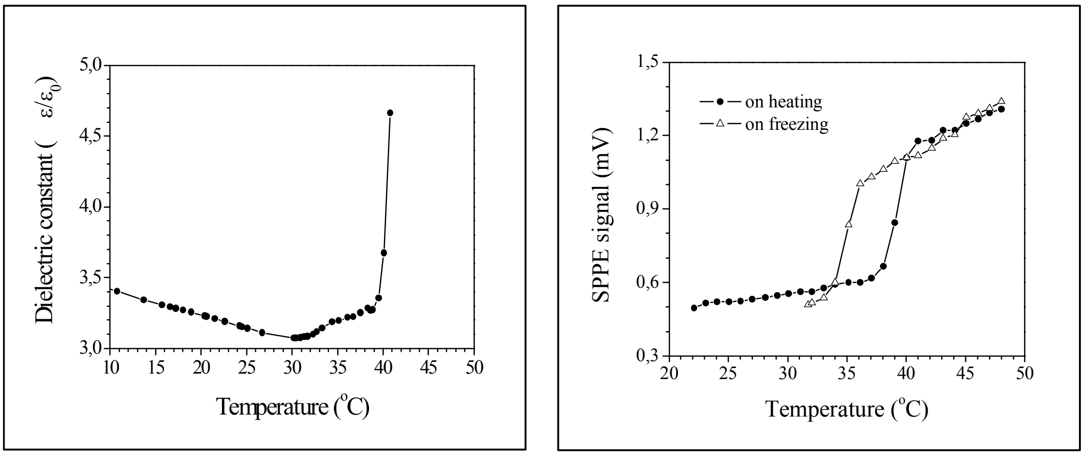


Figure 1. Schematic diagram of the experimental set-up used in simultaneous measurements.

3. RESULTS AND DISCUSSION

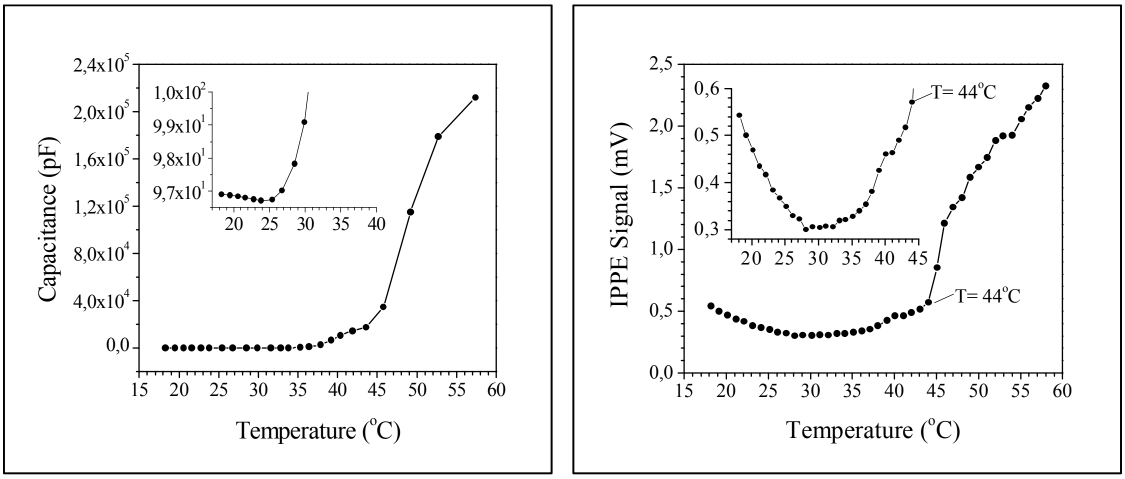
Figure 2 shows the results of separate, non-simultaneous measurements of dielectrical constant (Fig. 2a) and SPPE signal (2b) for margarine. More pronounced changes in both parameters are observed between 30^0C and 45^0C, an interval that encompasses major structural changes undergone by margarine. The LCR meter also measures electrical impedance and the current. The results (not shown) for both parameters confirmed the evidence for a major transformation in margarine within 30^0C to 45^0C range. Data collected indicate that at temperatures below that of major transition the system behaves as insulator with a high impedance and very low current.



a) b)

Figure 2. The independent, non-simultaneous measurements of a dielectric constant (a) and the photopyroelectric (standard PPE configuration) signal (b) for margarine platted versus the temperature.

In the range above the temperature associated with a major transition, the system behaves as a resistor having low impedance and high current. On the other hand the IPPE signal (Fig. 2b) shows that detection of major transformations is feasible. This figure also shows the reversibility changes on further cooling of the sample; similar conclusion can also be drawn from electrical parameters.



a) b)

Figure 3. Simultaneous measurements of the temperature dependent capacitance (a) and of IPPE signal (b).

Furthermore, the reversibility depends on the maximum temperature reached in a particular experiment. These experiments show that thermal and electrical parameters are sensitive to changes occurring in the sample exposed to a varying temperature.

The results (Fig. 3) acquired in simultaneous measurements with the combined set–up indicate the trend similar to that observed in the separate, non-simultaneous measurements. The capacitance in Fig. 3(a) and the IPPE signal in Fig. 3(b) show quite similar behaviour with regard to temperature variation. The data in Fig. 3a and 3b is obtained simultaneously from one and the same sample. This advantage feature gains significance when the objective of the research is to study details other than those associated with major transitions. The insets in Figs. 3 allow for the observation of additional details such as small signal disturbances present in either electrical or thermal signals. It is likely that these disturbances originate from changes in crystallization, differences in melting point of fat, onset of the process that breaks down the emulsions, changes in the orientation of dipoles of water during coalescence, etc.

Data obtained indicate that the configuration proposed here is suitable for detailed studies of melting process (it involves the melting of the fat, emulsion breakdown and the separation of oil-water as major processes) in margarine. The reliability achieved in the measurements performed with the set-up for simultaneous measurement was good. The methodology proposed is also applicable to any pasty-like fluid the properties of which change when the latter is exposed to varying temperature.

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